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LYSIMETER STUDIES ON THE LEACHING LOSSES OF NITROGEN, PHOSPHORUS, AND POTASSIUM

by

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INTRODUCTION

Soil is a complex physical, chemical, and biological system that supports vegetation. The role of nitrogen, phosphorus, and potassium in this complex has been the subject of exhaustive research. These elements play a major role in plant nutrition and are appropriately termed "major nutrient elements." With continuous and intensive crop production, the soil is being depleted of large quantities of these elements, but can be replenished by judicious fertilization and addition of crop residues. When large quantities of these elements are regularly applied, the unutilized nutrients, over a period of years, will amount to a considerable investment to the grower. However, losses due to fixation, volatilization, and leaching present a serious problem. Of these, the leaching or loss of nutrients in drainage water is of importance, at least in humid regions and areas with open textured soils which permit ready penetration of water. In such cases water moves through the soil profile carrying various solutes with it. The kind, magnitude, and cause of these losses, if known to the farmer, will greatly help him in modifying the cultural, manurial and cropping practices to suit his best interests.

Leaching losses are generally evaluated on a field scale by analyzing the soil and plants after a known amount of fertilizer application or through lysimeter investigations. The latter method involves the determination of percolation and nutrient losses from the soil, under somewhat controlled conditions. As

pointed out by Kohnke and Dreibelbis (1940), the correct use of lysimeters can answer many questions concerning pedology, soil fertility, and hydrology.

Exhaustive lysimeter investigations, under different soil and crop conditions, for periods ranging from a few days to several years, have been carried out to ascertain the fate and loss of plant nutrient elements, especially the nitrogen, phosphorus, and potassium in soil.

REVIEW OF LITERATURE

Leaching of Nitrogen

The natural supply of nitrogen in most soils is relatively meager. Soils are kept productive and continuous crop production is made practicable with manure and fertilizer applications. A large part of the applied element is probably utilized by the current crop and the rest of it is either utilized by soil micro-organisms or lost from the soil. These losses include the volatilization as ammonia and percolation losses of nitrates, since soils have virtually no adsorptive capacity for nitrates (Wadleigh and Richards, 1953). The loss of nitrogen in the percolate not only makes the soil less fertile, but also depletes the supply of bases to a considerable extent. Reviewing the fate of nitrogen in leaching losses, Raney (1960) noted a close correlation between nitrogen and bases in leachates ($r = 0.994$; 0.902; 0.898) under different conditions.

Wetselaar (1962), Burns and Dean (1964), and Johnston _et_ _al_.

(1965) noted the downward movement and loss of nitrogen in the drainage effluent. Harmsen and Van Schreven (1955) have presented information to point out the heavy leaching of mineral nitrogen as well, during the monsoon season, from different soils. Lysimeter experiments were carried out in Alabama, California, Connecticut, Cornell, Florida, Illinois, Ohio, Tennessee, and other places to evaluate the leaching losses of nitrogen under different conditions.

In Alabama, Jones (1942) observed a 33 to 65% leaching loss of added nitrogen from a sandy loam soil. The losses were greatly influenced by the kind of legume and time of turning it into the soil. Lysimeter studies at Riverside, California (Broadbent and Chapman, 1949, and Chapman et al., 1949), revealed substantial losses of nitrogen from legume treated and fertilized loamy soils. Greater losses were recorded from heavily fertilized plots. In Connecticut (Agricultural Experiment Station Annual Report '29/'30, 1931, Morgan et al., 1942), nitrogen losses from the soil in lysimeters ranged from 81 to 670 pounds per acre over a period of 10 years. The larger losses were on fallow ground or on soils which received nitrogen fertilizers. In other lysimeters, these losses were converted to gains when cover crops, in addition to regular cash crops, were used. Extensive lysimeter investigations were carried out at Cornell (Lyon and Bizzell, 1918, 1936; Bizzell, 1943, 1944), and percolation losses of nitrogen ranging from 40 to 313 pounds per acre per year were reported from uncropped soils. Cropping reduced the losses from a trace to 15 pounds an acre.

In Florida, Benson and Barnette (1939) observed the complete loss of nitrate nitrogen following the application of nitrogenous materials to different soils. In the case of a sandy soil, Volk and Bell (1945, 1947) observed percolation losses which exceeded the amount of nitrogen applied. Stauffer (1942) and Stauffer and Rust (1954) reported an average annual loss of 104 pounds of nitrogen per acre from eight uncropped Prairie group Illinois soils which had received no fertilizer for an extended period of time. Lysimeter studies in Ohio (Dreibelbis, 1946) revealed the importance of improved crop management practices in preventing leaching losses of nitrogen from silt loam soils. Lysimeter experiments on the recovery of fertilizer nitrogen from soils have been reported from the Tennessee Experimental Station. Recoveries of nitrogen in the percolate ranged from 74.7 to 93.0% of the applied nitrogen (Mooers _et al_., 1927; MacIntire _et al_., 1952). The leached nitrogen was in the form of nitrates. Losses averaged 86% for nitrogen applied as nitrate and 80% for nitrogen applied as ammonia over a period of 5 to 10 years. Allison _et al_. (1959) recorded 10 to 178 pounds loss of nitrogen per acre from a Lakeland sand during a 5-year study. Nitrate nitrogen comprised 85.2% of the nitrogen in the leachates. Studies elsewhere in western Australia (Drover, 1964) and Pretoria, South Africa (Theron, 1964) have also revealed considerable leaching losses of nitrogen.

In general, the amount of nitrogen lost by leaching is influenced by many factors such as soil type, methods of fertilization, cropping practices, and climate. Nitrogen occurred in the

percolate mainly in the form of nitrate (Lyon and Bizzell, 1918; Kohnke and Dreibelbis, 1940; Jones, 1942; Bizzell, 1943; Chapman et al., 1949; MacIntire et al., 1952). The loss of nitrogen as nitrite, ammonia, and other forms is almost negligible. Kohnke and Dreibelbis (1940) attribute the small percolate losses of ammonia to the large utilization of ammoniacal nitrogen by plants and fixation of the remainder in the exchange complex. If any ammonia is released from the exchange complex, it is readily oxidized before leaving the soil. However, these workers pointed out that considerable loss of nitrogen as ammonia occurs in percolates from peats and other soils where reducing conditions persist. Morgan (1936) and Benson and Barnette (1939) were of the opinion that the leaching of ammonium nitrogen varies directly with the base exchange capacity of the soil. Benson and Barnette noted a 40.3% loss of nitrogen in the ammoniacal form from a Norfolk sand which received ammonium sulfate as fertilizer.

The movement and loss of nitrate nitrogen is attributed to several factors. Burns and Dean (1964) point out soil porosity, the amount and movement of water, the cation associated with the nitrate, physical placement, amount of nitrate added, temperature, plant uptake and microbial activity as important factors in the movement and loss of nitrogen.

The importance of the rate and amount of percolating water in controlling the leaching losses of nitrates from the soil was emphasized by Lyon and Bizzell (1918). They observed greater loss of nitrates in years of large amounts of percolation and smaller losses in years of small percolation. Results reported by

Stauffer (1942) and Stauffer and Rust (1954) indicate a close correlation between the percolate and the loss of nitrogen from different soils ($r = 0.9701$ and 0.8726). Chapman _et al_. (1949) also noted greater leaching losses of nitrogen during the years of highest rainfall while no leaching was recorded in years with less than 10-inch rainfall. Owens (1960) concluded that the total amount of nitrogen lost through leaching was directly proportional to the amount of water applied and/or to the amount of water passing through the profile during spring months. He conducted lysimeter experiments using isotopic nitrogen. Benson and Barnette (1939) did not record the rate of percolation but recovered almost all the nitrate nitrogen applied in the leachates from Norfolk sand, Bladen fine sand, and Fellowship fine sandy loam, while Norfolk fine sandy loam retained 27.8% of the applied nitrogen. Similar differences due to soil type were also reported by Jones (1942). He evaluated the loss of nitrogen, applied by turning under legume crops, from lysimeters filled with Norfolk sandy loam, Hartsells fine sandy loam, and Decatur clay loam. Leguminous green matter was applied to supply 75 pounds of nitrogen per acre and the lysimeters were cropped with oats and vetch. The percolate loss of nitrogen was 5.9% of the applied nitrogen for the clay loam, while it averaged 45% for the sandy loam soils. The author attributed the greater loss on sandy loam soils to their smaller clay content and resulting poor texture. On the three soils, when oats were grown as a winter crop, only small amounts of nitrogen were lost by leaching. The production of Sudangrass as a summer crop on these soils also resulted in

considerable conservation of soil nitrogen as evidenced by the data presented in Table 1.

Table 1. Leaching losses of soil nitrogen as affected by crop growth (Sudangrass).

Treatment	Average annual loss of nitrogen		
	Norfolk fine sandy loam	Hartsells fine sandy loam	Decatur clay loam
	Lbs./A	Lbs./A	Lbs./A
No nitrogen fallow	30.3	52.8	31.5
No nitrogen Sudangrass grown during summer	15.9	14.6	3.4
Percent reduction due to cropping	47.5	72.4	89.2

At Cornell, leaching losses of nitrogen from cropped and fallow clay loam, sandy loam, and silt loam soils were studied over a 5- to 15-year period (Lyon and Bizzell, 1918, 1936). In general, greater amounts of water percolated through the fallow soils as compared to the cropped plots in all three soils. Their results are presented in Table 2, page 8.

Here again, cropping had greatly reduced the leaching losses of nitrogen from the three soils. Cropping practices resulted in a reduction of 94.0, 87.2, and 84.7% in leaching losses from the clay loam, sandy loam, and silt loam soils, respectively. While there was 33.3% less rainfall percolated through the cropped clay and sandy loam soils, cropping resulted in only an 8.6% reduction

in percolation through the silt loam. However, this did not seem to have any great influence. Lyon and Bizzell (1936) attributed the conservation of nitrogen on the cropped soils mainly to crop utilization and also to the nitrogen-assimilating microorganisms which derive energy from the organic matter liberated by the plant roots. Studying the cropping and fertilization in relation to the nitrogen losses from a silty clay loam, Bizzell (1944) concluded that timothy has effectively prevented the loss of significant quantities of nitrogen via leaching.

Table 2. Leaching of nitrate nitrogen from cropped and uncropped soils.

Treatment	Average annual loss of nitrogen		
	Dunkirk clay loam	Petoskey gritty sandy loam	Limed Volusia silt loam
	Lbs./A	Lbs./A	Lbs./A
No fertilizer fallow	102.71	313.1	43.0
Farm manure treated and cropped	6.20	40.1	6.6
Percent reduction in loss due to cropping	94.0	87.2	84.7

Volk and Bell (1945) conducted leaching experiments in lysimeters filled with sandy soils. When 100 pounds of nitrogen was applied as a mixed fertilizer, a turnip crop reduced the leaching loss of nitrogen by 87.4%. No great difference in leaching losses was observed between broadcast and band applications of the mixed fertilizer. Broadbent and Chapman (1949) and

Chapman *et al*. (1949) observed that the growth of legumes depressed leaching losses of nitrogen from both a fertilized and unfertilized loamy soil. Similar results were reported by Drover (1964), when a non-calcic brown soil was cropped with clover. In Pretoria, South Africa, Theron (1964) observed an average annual loss of 49.4 pounds of nitrogen per acre from an unfertilized fallow soil, while the percolate from fertilized and cropped (corn) lysimeters removed only 4.8 pounds of nitrogen per acre. Growth of the corn crop reduced the nitrogen losses by 90.3%.

Leaching of nitrogen from soil is affected by several factors including soil type, vegetation, rainfall, source of the nitrogen (nitrogen carrier), the anions or cations associated with the nitrogen in the carrier, and the quantity of nitrogen applied. Mooers *et al*. (1927) and MacIntire *et al*. (1952) carried out lysimeter investigations with different nitrogen carriers at the Tennessee Experimental Station. In these trials, 6,000 pounds of sodium nitrate per acre and equivalent quantities of other fertilizers were applied to uncropped lysimeters filled with a silt loam soil. Allison (1955) summarized their results. They are presented in Table 3, page 10. Losses averaged 86% for nitrate nitrogen and 80% for the ammonium salts. Among the three nitrate carriers applied, the loss of nitrogen from sodium nitrate was much more rapid than that from the equivalent amounts of calcium or magnesium nitrates. Among the ammonium salts, the recoveries of nitrogen were 79.6 and 74.7% for the chloride and phosphate, respectively, compared to 86.2% recovery from sulfate. Benson and Barnette (1939) studied the leachability of different

forms of nitrogen--nitrate, ammonium, nitrite, and urea--at various intervals following the application of nitrogenous materials to different soils. The trials were carried out in 3-gallon capacity glazed coffee urn type pots filled with 30 pounds of soil comprising a 9¼-inch soil column. Their results are presented in Table 4, page 11.

Table 3. Recovery of nitrogen from uncropped Cumberland silt loam in lysimeters at the Tennessee Experiment Station.

Form of nitrogen added	Nitrogen in leachates			
	Total	From fertilizer	Recovery	Average recovery
	Lbs./A	Lbs./A	%	%
First experiment--5 years				
No nitrogen	68.3			
Calcium nitrate	889.8	821.5	83.1	
Magnesium nitrate	871.1	802.8	81.2	
Sodium nitrate	987.4	919.1	93.0	85.8
Second experiment--12 years				
No nitrogen	372.8			
Ammonium chloride	1,160.1	787.3	79.6	
Ammonium phosphate	1,111.3	738.3	74.7	
Ammonium sulfate	1,224.7	851.9	86.2	80.2

Nitrogen applied as sodium nitrate was almost completely lost from three of the four experimental soils. Losses of nitrogen from the other carriers, ammonium sulfate, urea, and castor bean pomace were negligible except in the case of ammonium sulfate

applied to Norfolk sand.

Table 4. Leaching of nitrogen, 4 days after application, from different soils.

Source	Amount of applied nitrogen leached			
	Norfolk sand	Bladen fine sand	Fellowship fine sand	Norfolk fine sandy loam
	%	%	%	%
Sodium nitrate	97.9	96.8	98.6	72.9
Ammonium sulfate	40.3	3.1	4.9	0.5
Urea	2.6	-	1.0	0.1
Castor pomace	0.1	-	-	0.4

In another experiment these same workers studied the form and amount of nitrogen lost from a Norfolk sand 1, 4, 10, and 21 days after application of 80 pounds nitrogen per acre from different nitrogen carriers. The results are presented in Table 5.

Table 5. Percentage of total nitrogen leached at different intervals from Norfolk sand.

Source	Total nitrogen leached after			
	1 day	4 days	10 days	21 days
	%	%	%	%
Sodium nitrate	105.5	100.0	103.0	98.0
Calcium nitrate	97.1	95.2	105.3	96.1
Ammonium nitrate	70.5	67.4	76.1	73.6
Ammonium phosphate	10.9	16.7	9.5	4.9
Ammonium carbonate	3.1	-	4.0	14.8
Ammonium sulfate	32.0	42.8	35.1	41.7
Urea	35.1	16.4	3.8	18.7
Fish meal	0.2	1.7	5.9	12.1
Castor pomace	0.1	0.1	2.9	7.3
Tankage	0.4	0.7	1.4	3.3

The leaching losses of nitrogen were highest from applications of nitrate. These losses were practically independent of leaching time. The loss of nitrogen from the addition of insoluble organic fertilizers was insignificant initially but gradually increased with passage of time. Loss of nitrate nitrogen was greatest when associated with the sodium ion, closely followed by calcium and ammonium ions. Losses of nitrogen were comparatively lower from ammonium carbonate and phosphate as compared to urea and ammonium sulfate. The initial higher losses of nitrogen from urea tended to decrease with time, while in case of ammonium sulfate, they remained almost the same. Neither nitrite nitrogen nor urea leached to any great extent from any of the sources, except for 35 and 16% of applied urea lost as urea in the percolates collected 24 hours and 4 days after application. These same workers (Benson and Barnette, 1939) observed great variation in the leaching of nitrogen as ammonium. The results are presented in Table 6, page 13.

More nitrogen in the ammoniacal form was lost when ammonium salts were applied, with the exception of ammonium carbonate. Ammonium phosphate applications were marked by a decrease in the loss of ammoniacal nitrogen as time passed, while the losses remained almost the same throughout with the ammonium chloride and ammonium nitrate applications. Ammonium nitrogen losses from insoluble organic fertilizers were initially small but gradually increased with passage of time.

The influence of other cations and anions on the leaching of nitrogen and other nutrient elements was studied by Jacobson _et al._

Table 6. Loss of nitrate nitrogen and ammoniacal nitrogen from Norfolk sand at different intervals after application.

Source	Amount of nitrogen leached as nitrate after				Amount of nitrogen leached as ammonium after			
	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days
	%	%	%	%	%	%	%	%
Sodium nitrate	105.1	99.0	101.7	96.7	0.4	1.0	1.3	1.3
Calcium nitrate	94.1	91.4	100.4	91.3	3.0	3.8	4.9	4.8
Ammonium nitrate	53.2	52.0	58.0	55.0	17.3	15.4	18.1	18.6
Ammonium phosphate	0.3	2.7	1.2	2.3	10.6	14.0	8.3	2.6
Ammonium carbonate	-	-	3.4	8.8	3.1	-	0.6	6.0
Ammonium sulfate	-	0.9	2.0	2.0	32.0	41.9	33.1	39.7
Fish meal	-	-	3.3	2.4	0.2	1.7	2.6	9.7
Castor pomace	-	-	2.0	2.2	0.1	0.1	0.9	5.1
Tankage	0.3	-	0.7	1.5	0.1	0.7	0.7	1.8

(1948) in 9-inch deep cylindrical tanks filled with a sandy loam soil. A total of 1,000 pounds of nitrogen as urea, and 1,428.5, 868.5, 2,730.0, and 1,643.0 pounds of calcium, magnesium, potassium, and sodium, respectively, were applied per acre, over a 5-year period. Respective carbonate, sulfate, chloride, and phosphate salts were used. The different nitrogen fractions in the leachates, as influenced by these groups, are presented in Table 7, page 15.

Nitrate nitrogen was the dominant fraction in leachings from all cylinders regardless of the anion group present. Losses of total and nitrate nitrogen were somewhat higher in the presence of phosphate. Chloride, on the other hand, apparently enhanced the accumulation of total and nitrate nitrogen but increased the loss of ammonium nitrogen.

Bizzell (1943) noted heavier losses of nitrogen from a sandy loam soil treated with sodium nitrate as compared to ammonium sulfate, but later (Bizzell, 1944) recorded only insignificant loss of applied nitrogen from cropped Dunkirk silty clay loam, irrespective of the quantities of sodium nitrate applied. Volk (1956) also recorded only small nitrogen losses from lysimeters filled with Lakeland fine sand when urea and ammonium nitrate were applied to supply 240 and 480 pounds of nitrogen per acre. The lysimeters were cropped with pasture grasses and consequently rainfall caused little leaching.

Nitrogen losses were higher in general, at higher rates of fertilizer application (Broadbent and Chapman, 1949, and Chapman _et al_., 1949) and from fertile soils (Raney, 1960). Liming of a

Table 7. The influence of various anions on the leaching of nitrogen fractions from Merrimac sandy loam over a 5-year period.

Anion group	Nitrogen fractions in leachates						Total N	Loss or conservation
	NO_3-N	Loss or conservation	NH_4-N	Loss or conservation	NO_2-N	Loss or conservation		
	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A	Lbs./A
Urea alone	1,036		47		12		1,095	
Carbonate group	1,119	-83	16	31	34	-22	1,169	-74
Sulfate group	1,066	-30	75	-28	12	Nil	1,153	-58
Chloride group	969	67	86	-39	12	Nil	1,067	28
Phosphate group	1,127	-91	39	8	12	Nil	1,178	-83

soil did not result in any reduction in percolated water or nitrogen loss from a fallow silt loam and sandy loam soils (Lyon and Bizzell, 1936).

Leaching of Phosphorus

Among the three major plant nutrients, phosphorus is the only element that is not readily lost from the soil in leachates. The ability of soils to retain applied phosphorus is well known. When fertilizers are applied, phosphorus is commonly retained in the surface layers of soil and firmly held against the leaching action of rain and water. As much as 68 to 78% fixation was noted within 24 hours of application by Sen Gupta and Cornfield (1963). Investigations of Midgley (1931), Brown (1935), Schaller (1940), Doak (1942), Lutz _et_ _al_. (1956), and MacKay and Eaton (1959) revealed that phosphorus migration in soils was very limited. In lysimeter experiments that have been set up at various places to study leachate losses, phosphorus is the only major nutrient element that has not been recovered except to a slight degree (Lyon and Bizzell, 1918, 1936; Broadbent and Chapman, 1949; Pratt and Chapman, 1961; and Drover, 1963).

Chemical analyses of soil samples from some long-term phosphorus experiments have indicated appreciable penetration of phosphorus to the 1-foot level and below under some conditions (Stephenson and Chapman, 1931; Sell and Olson, 1947; Pratt _et_ _al_., 1956). Also, some investigators recovered applied phosphorus to some extent in water soluble forms. Thomas (1935) obtained considerable water-soluble phosphorus from Hagerstown silty clay

loam that had been heavily phosphated. Bryan (1933) and Peech (1939) recovered appreciable amounts of phosphorus in 1:5 soil-water extracts of soils, chiefly the Norfolk sands of citrus groves, that had received applications of superphosphate for a number of years. Bryan noted that the content of water-soluble phosphorus in sands was much higher than in sandy loams and loams similarly phosphated. Hagin (1957) observed a considerable amount of applied phosphorus in water-soluble form 4 weeks after application to a sandy soil. It is probable that in regions of heavy rainfall this available phosphorus may be lost in leachates. This is a problem especially in coarse textured soils which have low base exchange capacity and no ability at all to fix phosphorus.

Ozanne _et_ _al_. (1961) reported huge losses of applied phosphorus from a loamy sand cropped with pasture, which had received 22 inches of rainfall. When superphosphate was applied broadcast to supply 42 to 389 pounds of total P per acre, a loss of 17 to 81% of the phosphorus occurred from the top 4-inch soil zone. Only with the application of rock phosphate did the phosphorus retention capacity of the soil increase from 56 to 85%. Opinions expressed by Collings (1938), Bear (1948), and Black (1957) and investigations by Converse (1948), Cooke and Gasser (1955), and Hingston (1959) support the possibility of downward movement and leaching losses of applied phosphorus from sandy soils. From their laboratory leaching studies, Hogg and Cooper (1964) reported 22 and 36% leaching losses of phosphorus from a Te Kopuru sand.

Neller (1946) carried out extensive lysimeter investigations

to determine the mobility of phosphorus in different soils. He recorded 80 to 90% loss of applied phosphorus from Leon fine sand. His results from different soils are presented in Table 8.

Table 8. Percentage leaching of citrate-soluble phosphorus from different types of soils, from May 10 to September 4, 1945.

Soil type	Percent of applied phosphorus leached when applied as	
	Superphosphate*	Calcined phosphate*
Norfolk fine sandy loam	6.30	1.84
Dunbar fine sandy loam	1.79	1.88
Coxville clay	1.59	1.86
Bladen fine sandy loam	1.79	1.32
Amite fine sandy loam	Trace	1.31
Plummer fine sand	20.28	34.52
Leon fine sand	90.61	81.35

*To supply 1200 pounds of citrate-soluble phosphorus per acre.

A total of 81.35% of the citrate-soluble phosphorus of calcined phosphate, and 90.61% of that of superphosphate were recovered in the leachates from Leon fine sand. The recoveries from Plummer fine sand were 34.52 and 20.28%, respectively. Those from the clay and sandy loams varied from a trace to less than 2%, except that of superphosphate on Norfolk fine sandy loam which was 6.30%.

In an elaborate lysimeter study conducted by Jacobson _et al._ (1948), only traces of phosphorus were lost from a sandy loam that did not receive any fertilizer phosphorus, but many times the amount was lost from tanks receiving phosphorus fertilizer. The loss of phosphorus from different carriers, when applied at

the rate of 2,216 pounds of phosphorus per acre is presented in Table 9.

Table 9. Leaching losses of phosphorus from Merrimac sandy loam over a 5-year period when supplied at the rate of 2,216 pounds of phosphorus per acre.

Source of phosphate	Amount of phosphorus leached
	Lbs./A
$Ca\ (H_2Po_4)_2 \cdot H_2O$	40.6
$Mg\ (H_2Po_4)_2 \cdot H_2O$	94.0
$K\ H_2Po_4$	178.0
$Na\ H_2Po_4 \cdot H_2O$	272.7

The phosphorus loss was influenced most by sodium followed by potassium, magnesium, and calcium. Similar differences were also noted by Neller (1946). When superphosphate, calcined phosphate, and rock phosphate were applied to a limed Leon fine sand, at the rates of 313, 625, and 1,250 pounds per acre, the losses averaged 79.1 and 82.9% of phosphorus for superphosphate and calcined phosphate, respectively, as compared to 8.9% of phosphorus for rock phosphate applications. Details are given in Table 10, page 20.

Neller and Bartlett (1957) compared the availabilities and mobilities of different phosphates applied to a limed, cropped Lakeland fine sand (P^H 5.8). The leachates were collected from April 29 to August 4. During this period rainfall totaled 17.6 inches. Their results are presented in Table 11, page 20.

Table 10. Leaching of applied phosphorus from limed Leon fine sand fertilized with various phosphates at three levels (May 10--September 4, 1945).

Source	Rate	Phosphorus leached*	Average recovery
	Lbs./ac	%	%
Superphosphate	313	76.06	
	625	91.20	
	1,250	70.15	79.1
Calcined phosphate	313	98.52	
	625	87.75	
	1,250	62.35	82.9
Rock phosphate	313	10.47	
	625	10.14	
	1,250	6.19	8.9

*Based upon equivalent amounts for a given rate per acre of citrate soluble phosphorus, except for rock phosphate which is based upon total phosphorus content.

Percolate losses of phosphorus were less at higher rates of calcined phosphate and rock phosphate applications; whereas, loss from superphosphate was highest at the 625 pounds per acre application.

Table 11. Leaching of applied phosphorus from limed Leon fine sand, cropped with millet.

Phosphate type	Mesh	Applied phosphorus leached
		%
Tricalcium	10	12.19
Tricalcium	40	33.27
Dicalcium	Fine	31.37
Rock	50% - 200	0.015
Rock	85% - 200	0.24
None	None	None

A total of 33.27% of the phosphorus from fused 40-mesh tricalcium phosphate was recovered in the leachates, whereas 10-mesh phosphate yielded 12.19% of its phosphorus. The dicalcium phosphate lost 31.37% of its phosphorus. Leaching losses from the ground rock phosphate were negligible, especially from the material ground, to permit 50% to pass a 200-mesh sieve. The phosphorus utilization by the crop was also greater from tricalcium and dicalcium phosphates than from rock phosphate. In another experiment on the same soil, these authors noticed only small percolate losses of phosphorus but suggested that rains were not intense enough, during that period, to cause leachings.

Considerable leaching losses of phosphorus were also reported from organic soils. Larsen <u>et al</u>. (1958) studied the leaching of applied phosphorus from five organic soils and one mineral soil, using labeled phosphate. When labeled phosphorus was mixed into the surface 2 inches of a 14-inch column of a virgin organic soil, 60 and 80% appeared in the leachate from 15 and 30 inches of water, respectively. After 15 inches of water were leached through the soil columns, phosphorus retention closely related to the sesquioxide content of the soils and apparent degree of decomposition. Lesser amount of phosphorus appeared in the leachate from soils with greater sesquioxide contents and with longer drainage histories, while no fertilizer phosphorus was leached from the mineral soil or from the organic soil which had been drained for 15 or more years.

Besides the source of phosphorus, intensity of rainfall, and the sesquioxide content of the soil, the native phosphorus and

organic matter content of the soil also play a considerable part in controlling the percolate losses of phosphorus. On a loamy sand, Ozanne <u>et</u> <u>al</u>. (1961) noted a significant negative correlation between leaching loss of applied phosphorus and native phosphorus (r = -0.93) and ignition loss (r = -0.95). They conclude that soils containing less than about 100 ppm. of native phosphorus or giving less than about 6% loss on ignition, are liable to lose considerable quantities of fertilizer phosphorus. This opinion was amply supported by the observations of several other workers, whose results are presented in Table 12.

Table 12. Soil phosphorus, organic matter, and leaching losses.

Work of	Soil analyses: Native P	Soil analyses: Organic matter	Loss of applied phosphorus
	Ppm.	%	%
Neller (1946)	27	3.0	90
Neller <u>et</u> <u>al</u>. (1951)	80	3.2	85
Mingston (1959)	20	2.6	71
Doak (1942)	420	10.2	23
Walker <u>et</u> <u>al</u>. (1959)	470	$\simeq$ 18.0	<20
Saunders (1959)	2300	$\simeq$ 20.0	Nil

Although conflicting opinions exist concerning the utility of lime on different soils in preventing the leaching losses of phosphorus, on Leon fine sand (P^{H} 4.5) at least, it was found to be effective by Neller (1946). The leachates were collected over a period of 117 days. His results are presented in Table 13, page 23.

Table 13. Influence of lime on the leaching of applied phosphorus from Leon fine sand.

Source	Amount of phosphate per lysimeter	Phosphorus leached	
		Lime added*	No lime
	gm.	%	%
Superphosphate	3.976	70.15	90.61
Calcined phosphate	3.976	62.35	81.35
Ground rock phosphate	5.592	10.47	46.88
"	11.183	10.14	48.27
"	22.365	6.19	27.28
"	5.592	1.26†	46.88

*At the rate of 1 ton per acre (P^H increased from 4.6 to 5.5).

†Two tons of lime per acre (P^H increased from 4.6 to 6.35).

Liming caused a marked decrease in the percolate losses of applied phosphorus, from all the three sources. In case of ground rock phosphate, it reduced the percentage loss more for the heavier than for the lighter rates of application. With an application of 2 tons of lime per acre, only 1.26% of the total phosphorus of rock phosphate was recovered in the leachate as compared to 46.88% without lime.

Leaching of Potassium

As greater emphasis is being laid on higher crop yields and increased use of acid-forming nitrogen fertilizers, the loss of bases from the soil has become a factor of major concern. Raney (1960) observed a close correlation between nitrogen in leachates and potassium, calcium, and magnesium in leachates (r = 0.994,

0.902, and 0.898) for different soils. When a soluble potassium salt is added to the soil, it becomes dissolved in the soil solution. Part of it is utilized by the current crop, and some may be held by the base exchange reactions in an exchangeable form. A part may remain in available form (Nelson and Stanford, 1958).

The migration of available potassium to regions below subplow horizon along with drainage water is not uncommon (Peterburgsky and Yanishevsky, 1961). Truog and Jones (1938) reviewing the fate of applied potassium to soils, suggested that leaching losses range from 10 to 15 pounds per acre. Nelson and Stanford (1958) concluded that leaching losses of potassium are considerable from sandy soils. Lysimeter investigations carried out at different places showed substantial losses of potassium from coarse textured soils, and under fallow conditions from finer textured soils. Among the three major nutrient elements, N, P, and K, the percolate losses of potassium rank next to nitrogen.

Lyon and Bizzell (1918, 1936) recorded an average annual loss of 60.6, 73.3, and 87.2 pounds of potassium per acre from lysimeters filled with sandy loam, clay loam, and silt loam soils, respectively. The lysimeters were kept fallow but received 10 tons of farm manure. Blume and Purvis (1939) recovered 28.0, 35.2, and 39.7% of applied potassium during a 5-month period, from fallow loamy fine sand, sandy loam and silt loam soils, respectively, when the lysimeters received 50 to 1,600 pounds of K_2O per acre. Losses of lesser magnitude were reported by Stauffer (1942) and Stauffer and Rust (1954) from lysimeters filled with different silty clay soils in Illinois. Stauffer

and Rust (1954) noted significant (1%) correlations between the annual loss of percolate and potassium. Stauffer (1942) considered the amount of drainage as influenced by rainfall to be an important factor in the leaching of potassium.

Volk (1940) measured the leaching of exchangeable potassium from Norfolk fine sandy loam, Hartsells very fine sandy loam, and Decatur clay that received potassium applications of 80, 160, 320, and 640 pounds per acre during a period of 8 years. The two coarser soils lost about 3 to 4 times as much of the applied potassium, as did the Decatur soil. The percentage losses at the highest rate of application for the three soils were 34, 31, and 9%, respectively.

Sandy soils permit ready percolation of water. Since most of the soil potassium is in the available form, relatively rapid and high losses of potassium from sandy soils have been reported. Kime (1944) studied the leaching of potassium from a sandy citrus soil of Florida. He observed the complete loss of easily leachable potassium with an equivalent application of 4-acre inches of rain. Potassium apparently leached at two rates: the first and most rapid rate was 3 to 8% per acre inch of rainfall; the second and lower rate of leaching was 1 to 3% per acre inch of rain. He attributed the former to the solution of potassium salts and the latter to the replacement of exchangeable potassium, decomposition of organic matter, and dispersion of humates. He also noted increased loss of potassium at P^H's below 5.3 or above 6.0. Peech and Bradfield (1943) have shown this to be true for clay soil as well. Volk and Bell (1944) emphasized the importance of soil P^H

in retention of soil potassium, especially in soils with lower base exchange capacities.

Allison _et_ _al_. (1959) noted a 69.4 pound per acre loss of potassium from a fallow Lakeland sand that did not receive any fertilizer potassium and 105.8 pounds from a plot that has received 80 pounds of K_2O over a 5-year period. Hogg and Cooper (1964) recovered 22% of the potassium applied as muriate of potash in leachates collected after a period of 4 weeks from Te Kopuru sand.

Considerable reduced percolate losses of potassium were noted from different soils that were under some kind of vegetation or cropping system (Lyon and Bizzell, 1918, 1936; Volk, 1940; Volk and Bell, 1945; Allison _et_ _al_., 1959; and Theron, 1964). Dreibelbis (1946) emphasized the importance of improved crop management practices to conserve soil potassium. A good vegetative cover on the soil is helpful, since the plants utilize nutrients and also reduce the percolate losses of water. Pratt and Chapman (1961) observed only very small percolate losses of potassium from an unfertilized, cropped Sierra loam over a period of 20 years. Lyon and Bizzell (1918, 1936) and Volk and Bell (1945) observed 24.6, 28.9, and 88.0% reductions in percolate losses of potassium due to cropping, from a clay loam, sandy loam, and sandy soil, respectively.

Allison _et_ _al_. (1959) reported an 80% conservation of applied potassium due to various crop treatments on a Lakeland sand. The losses of potassium under some crops are presented in Table 14, page 27.

Table 14. The potassium content of percolates from a Lakeland sand under different cropping conditions (3-year total).

Crop	Total K_2O applied as Kcl	Total loss of K_2O in percolate
	Lbs./A	Lbs./A
None	None	69.4
None	80	105.8
Millet	48*	44.5
Crotalaria	80†	24.3
Corn and millet	80	24.3
Crotalaria and millet	80‡	18.9
Cowpeas and millet	80	18.3
Cowpeas, millet, and rye	80	18.1

*Additional potassium, not determined, was added in animal manures.

†Average for two lysimeters.

‡Average for three lysimeters.

Smaller percolate losses were observed with larger crops. Decreased losses of potassium from some lysimeters may be attributed to this.

Among the different leguminous crops they have grown, Pratt and Chapman (1961) noted the conservation of potassium to be in the decreasing order of vetch, mustard, and melilotus. Lyon and Bizzell (1918) recorded a 45.8% reduction in the loss of potassium by including clover in a rotation while the rotation without clover could reduce the loss by only 28.1%.

Besides vegetation, the most important factor determining percolate losses was the amount of available potassium present in the soil. This in turn is dependent on the amount of potassium applied. Investigating the fixation and release of applied potassium from three Coastal Plains soils, Blume and Purvis (1939)

recovered 25 to 56.1% of applied potassium in leachates, the highest loss being at higher levels of potassium application. Their results are presented in Table 15.

Table 15. Leaching loss of potassium at different levels of application, from three Coastal Plains soils.

K_2O applied	Percent of applied potassium leached		
	Portsmouth loamy fine sand	Sassafras sandy loam	Elkton silt loam
Lbs./A			
50	27.9	25.4	25.0
100	26.0	37.6	37.5
200	26.1	42.0	36.5
400	30.0	34.2	33.5
800	26.4	40.1	49.4
1600	31.9	41.7	56.1

In the case of the Portsmouth soil, the percent loss of potassium was almost the same at all levels of application. However, in the case of the Sassafras sandy loam and the Elkton silt loam, there was a tendency for the losses to increase with increased applications. This does not seem to be true on all soils. MacIntire _et al_. (1945) observed a greater loss of potassium when potassium sulfate was applied at the rate of 200 pounds of K_2O per acre rather than at a rate of 1,000 pounds of K_2O per acre. On the fine sandy loam and silt loam soils studied, the losses were respectively 49.5 and 46.0% of the application at the lower rate while only 40.7 and 29% losses were noted at the higher rate.

Volk and Bell (1945) reported that the band placement of 83 pounds per acre of K_2O resulted in leaching losses 168% greater

than that from a broadcast application of the same magnitude on Norfolk loamy fine sand.

The characteristics of the potassium fertilizer, its relative solubility, the relative mobilities of anions associated with it, the fixing capacity of the soil, and various other anions and cations present in the soil, control to a considerable extent the ease and rapidity of potassium loss in soil percolates. Studying the divergent behavior of KPO_3 and K_2SO_4 in soils, MacIntire _et al_. (1945) recovered greater amounts of potassium from 200 pounds of K_2O supplied as K_2SO_4 on a fine sandy loam and silt loam soils. Their results are presented in Table 16.

Table 16. Loss of potassium applied as KPO_3 and K_2SO_4.

Soil	Loss of potassium from 200 pounds of K_2O applied as		Increased loss due to K_2SO_4
	KPO_3	K_2SO_4	
	%	%	%
Hartsells fine sandy loam	38.5	49.5	28.6
Fullerton silt loam	29.5	46.0	55.9

Greater losses of potassium, when applied as K_2SO_4, were noted on Fullerton silt loam as compared to Hartsells fine sandy loam. Jacobson _et al_. (1948) also recovered more potassium when the element was applied as salts with more mobile anions. Their results are presented in Table 17, page 30.

The loss of potassium was highest when it was applied to the

soil as the chloride or sulfate and relatively lower when applied as the phosphate and carbonate. The greater losses with the former two salts may be due to the ease with which the chlorides and sulfates are washed out of soil profile. Investigations of Hogg and Cooper (1964) lent support to this presumption. They recovered 22% of potassium applied as Kcl, as compared to only 8% recovery from $KHCO_3$ applications to Te Kopuru sand.

Table 17. Percolate losses of potassium from Merrimac sandy loam that received different potassium fertilizers over a 5-year period.

Source*	Amount of potassium lost	
	Total for 5 years	Percent lost
	Lbs./A	
Kcl	1693	51.6
K_2SO_4	1633	49.4
KH_2PO_4	1482	44.0
K_2CO_3	1431	42.2

*To supply 2,793 pounds potassium per acre in 5 years.

Nitrates in the soil and nitrogen fertilizers applied may also play an important role in the leaching of potassium. Raney (1960) pointed out a close correlation between nitrogen in leachates and bases in the percolate. Results reported by Allison <u>et al</u>. (1959) revealed a significant correlation between nitrogen in the percolate and potassium (r = 0.8836*). Jacobson <u>et al</u>. (1948) recorded an annual average loss of 50.6 pounds potassium per acre when a sandy loam soil was treated with 200 pounds of

nitrogen per acre as urea. Broadbent and Chapman (1949) and Pratt and Chapman (1961) recorded progressive increases in the loss of potassium with increased applications of nitrogen as $Ca(NO_3)_2$ to a loamy soil that did not receive any fertilizer at all.

MacIntire _et_ _al_. (1938, 1952) carried out lysimeter investigations with different nitrogen carriers and recorded the removal of potassium. The lysimeters were filled with Cumberland silt loam and received 6,000 pounds of sodium nitrate or its equivalent. The results are presented in Table 18.

Table 18. Removal of potassium from uncropped Cumberland silt loam in lysimeters, when different nitrogen carriers were applied in equivalent quantities of 6,000 pounds of sodium nitrate per acre.

Form of nitrogen added	Potassium in leachates: Total	Potassium in leachates: Due to nitrogen fertilizer	Percent increase	Average
	Lbs./A	Lbs./A		
First experiment - 9 years				
No nitrogen	118	-		
Sodium nitrate	185	67	56.8	
Calcium nitrate	164	46	39.0	
Magnesium nitrate	156	38	32.0	42.6
Second experiment - 12 years				
No nitrogen	158	-		
Ammonium chloride	296	138	87.3	
Ammonium sulfate	249	91	57.6	
Ammonium phosphate	230	72	45.6	63.5

When equivalent quantities of nitrogen were applied, losses of potassium were higher in the presence of applications of ammonium salts as compared to nitrates. Ammonium chloride application was accompanied by the most potassium loss, followed by ammonium sulfate and phosphate. Among the various nitrates supplied, sodium nitrate apparently replaced the most potassium, followed by calcium and magnesium nitrates.

Divergent opinions were expressed on the influence of lime in controlling the availability and losses of potassium. The exchangeable-soluble Ca-K relationships and the physiological interactions of these two cations aroused considerable discussion. Reitemeyer (1951) has provided an excellent discussion on lime and potassium relationships in his review on soil potassium. Whereas Jenny and Shade (1934) opined that lime liberated potassium from soils into soluble forms, Lyon and Bizzell (1918, 1936) noted no increased losses of potassium in the leachates and concluded that liming did not liberate soil potassium. Blume and Purvis (1939) noted considerable reduction in the loss of applied potassium from different limed soils but attributed the smaller losses of potassium to the improved soil structure and consequently small percolate losses of water.

MacIntire _et al_. (1927, 1943) conducted extensive investigations on the effect of lime and Ca salts on the solubility of soil potassium. They reported that neutral salts of Ca can liberate potassium to the leachings of an acid soil, but that this does not result from calcium oxide or magnesium oxide applications. Mann and Barnes (1940) observed considerable leaching

losses of potassium from an acid soil during 50 years of wheat and barley cropping, but the addition of lime decreased potassium in the leachates.

MacIntire et al. (1945) have amply shown that additions of limestone and dolomite have induced a substantial repression in the leaching of both native and fertilizer potassium from a fine sandy loam and silt loam soils. Their results are shown in Table 19.

Table 19. Influence of lime on soil losses of potassium supplied as KPO_3 and K_2SO_4.

Liming material*	Loss of potassium (Pounds/2,000,000 pounds soil)				
		200 lbs. K_2O		1,000 lbs. K_2O	
	NO K	KPO_3	K_2SO_4	KPO_3	K_2SO_4
	(Hartsells fine sandy loam)				
None	19	96	118	426	321
Limestone	5	23	29	295	134
Dolomite	6	25	-	348	-
	(Fullerton silt loam)				
None	55	114	147	345	264
Limestone	30	87	98	407	240
Dolomite	31	83	-	380	-

*To supply 2,775 and 5,000 pounds $CaCO_3$ per acre on Fullerton silt loam and Hartsells fine sandy loam, respectively.

Leachate compositions demonstrated that recovery of potassium from KPO_3 is less than that from K_2SO_4 at the 200-pound K_2O rate on both soils, unlimed, limed, and dolomited. At the 1,000 pound K_2O rate, recovery of potassium from KPO_3 was invariably greater. Both lime and dolomite applications reduced the

potassium loss from both soils treated with both potassic fertilizers. However, when Fullerton silt loam was treated with 1,000 pounds of K_2O per acre as KPO_3, losses of potassium were seemingly enhanced by liming with either calcitic or dolomitic limestone. The authors attributed the heavy loss to the greater precipitation of Ca and Mg induced by KPO_3 at the heavy rate accompanied by an enhancement in sulfate leaching and the resultant loss of potassium as potassium sulfate.

DISCUSSION

Water cannot move through the soil profile without carrying solutes with it. The amount and kind of nutrients lost in this manner depends on soil texture, structure, temperature, P^H, base exchange capacity, the anions and cations present in the soil, vegetation, fertilizer application, type and quantity of fertilizer applied, method and time of fertilizer application, and rainfall, its amount, intensity, and distribution.

Nitrogen

Percolation losses of nitrogen are higher than those of phosphorus and potassium. The majority of this nitrogen is lost as nitrates since these ions are not held by the exchange complex to any great extent (Wadleigh and Richards, 1953). Losses of nitrogen as nitrite and urea are almost negligible. Due to soil fixation, plant utilization, and volatilization, leaching losses of ammonia are minimal except from soils with reducing powers and under conditions favorable for denitrification. Jacobson _et_ _al_.

(1948) attributed the higher losses of ammonium nitrogen (Table 7) after the application of chloride and sulfate salts of Ca, Mg, K, and Na to the retardation of nitrification of urea at the lower soil P^H's produced by the two anionic groups mentioned. These studies were carried out on a sandy loam which permitted leaching losses of nutrients. In the same experiment, losses of nitrogen as nitrate were higher than those of ammonium nitrogen when the carbonates and phosphates salts were supplied to the soil. This phenomenon was suggested to be the result of rapid transformation of ammonia nitrogen to nitrates at higher soil P^H's which resulted from the application of ammonium carbonates and phosphates of Ca, Mg, K, and Na. Further, the findings of Morgan (1936) and Benson and Barnette (1939) indicate a direct relationship between the base exchange capacity of the soil and percolate losses of ammonium nitrogen. In soils with greater base exchange capacities, ammonium may be retained by fixation against leaching losses. Forty percent of the nitrogen present as ammonia was lost in the percolate from a Norfolk fine sand that received ammonium sulfate, whereas none was lost from Norfolk fine sandy loam similarly treated.

Investigations of Lyon and Bizzell (1918), Jones (1942), Bizzell (1943), Chapman et al. (1949), and MacIntire et al. (1952) have shown nitrate nitrogen as the dominant form of nitrogen in soil percolates. The rate and amount of percolation through the soil profile to a large extent determines the loss of this element. Results of Stauffer (1942), and Stauffer and Rust (1954) have revealed a close correlation (r = 0.9701 and

0.8726) between the percolate and nitrogen losses from the soil. Investigations of Lyon and Bizzell (1918), Chapman *et al.* (1949), and Owens (1960) indicated higher leaching losses of nitrogen during years of heavy rainfall and vice versa.

Coarse textured soils have low base exchange capacities and also permit ready percolation of water. Invariably, losses of nitrogen from coarse textured soils are high. Allison *et al.* (1959) noted a loss of up to 178 pounds of nitrogen from a cropped sandy soil, in their 5-year study, and emphasized the importance of the total amount of nitrogen present in the soil when leaching occurred.

Jones (1942) attributed higher losses of nitrogen from Hartsells fine sandy loam and Norfolk fine sandy loams as compared to Decatur clay loam to the absence of clay in the two former soils and the resultant poor texture. Bizzell (1944) detected only negligible amounts of nitrogen losses from a clay loam that received different quantities of sodium nitrate. Greater nitrogen losses from a sandy loam as compared to silt and clay loams were also observed by Lyon and Bizzell (1918, 1936). No great differences were observed by Benson and Barnette (1939) in the percolate losses of nitrogen from Norfolk sand, Bladen fine sand, and Fellowship fine sandy loam (Table 4) that have received sodium nitrate. Percolation losses of nitrogen ranged from 96.8 to 98.6% of the applied nitrogen. No mention was made as to the rate of percolation, however. Percolation differences, if any, due to the texture of the soils, would have been obviated by the ready and complete loss of nitrogen applied

as sodium nitrate, since all these soils permitted considerable percolation of water.

Vegetative soil covers aid in reducing leaching losses of nitrogen. Plants utilize nitrogen and also help reduce percolation. Lyon and Bizzell (1936) considered nitrogen assimilating microorganisms to be an important factor in nitrogen retention. The fact that cropping can reduce percolation and nitrogen losses was shown by Lyon and Bizzell (1918, 1936), Bizzell (1944), Volk and Bell (1945), Pratt and Chapman (1949), Chapman et al. (1949), Drover (1964), and Theron (1964). The reduction in percolation losses of nitrogen ranged from 47.5 to 94% (Tables 1 and 2), the highest being in the case of clay loams.

Raney (1960) noted that the amount of nitrogen that leached out of Lakeland sand was more closely associated with the total amount added as fertilizer or by nitrogen fixation than with the crop removal and expressed little hope of adjusting cropping system to reduce the leaching losses of nitrogen. Since sandy soils are very low in base exchange capacity, split applications of fertilizer to growing crops, avoiding heavy rainfall periods, may be helpful in reducing nitrogen losses. Broadbent and Chapman (1949) reported that nitrogen losses were higher from fertile soils and those receiving higher rates of fertilizer application. Presumably, this is due to the large amount of nitrogen present in the available form. Improved crop management practices such as keeping the soil under vegetation as completely as practicable will go a long way in reducing the percolation losses of nitrogen from different soils.

The relative solubility of the fertilizer and the mobility of the cations and anions associated with nitrogen play an important role in nitrogen losses. When equivalent quantities of nitrogen were applied, losses from insoluble organic fertilizers such as fish meal, castor pomace, and tankage (Table 5) were almost nil initially. The losses increased with time, indicating that more and more had become available from these sources due to mineralization. Among the various inorganic fertilizers that were applied, nitrate nitrogen was readily and completely lost via percolation, while losses of nitrogen from ammonium salts and urea were small.

Among the different sources of nitrate nitrogen utilized in leaching studies, losses from sodium nitrate were greater than those from calcium, magnesium, and ammonium nitrates (Mooers _et al_., 1927; Benson and Barnette, 1939; and Bizzell, 1963). This grouping with sodium at the top is to be expected due to the relatively high mobility of this cation. Similar conclusions can be drawn from the anions associated with the ammonium ion. Twenty-one days after the application of ammonium nitrate and ammonium sulfate to a Norfolk sand, Benson and Barnette (1939) noted (Table 5) losses of 74 and 42% of the applied nitrogen, respectively. Losses of nitrogen from ammonium carbonate and ammonium phosphate applications were only 15 and 5%, respectively. MacIntire _et al_. (1952) recovered 86, 80, and 75% of the nitrogen applied as ammonium sulfate, ammonium chloride, and ammonium phosphate, respectively. These are also in accordance with their leachable abilities (Wadleigh and Richards, 1953). In general,

the relative leachability of nitrogen from the different nitrogen carriers can be arranged in the following decreasing order: sodium nitrate, calcium nitrate, magnesium nitrate, ammonium nitrate, ammonium sulfate, ammonium chloride, urea, ammonium phosphate, ammonium carbonate, and insoluble organic fertilizers.

Careful crop and fertilizer management to include adequate plant cover and split applications of fertilizer when necessary will go a long way in reducing leaching losses of this important nutrient element.

Phosphorus

Phosphorus is the one element that is not generally found in appreciable quantities in the percolates collected from various lysimeters located at different institutions. Various soil factors contribute to the retention of soil phosphorus. Important among them are soil type, native phosphorus content, organic matter and sesquioxide content, base exchange capacity, calcium carbonate content, nature and amount of phosphorus applied, and the method of application.

Most of the percolate losses of phosphorus have been recorded from coarse textured soils. These soils do not have good phosphorus retentive capacities and permit rapid percolation of water as well. A large amount of available phosphorus is generally lost in the drainage from such soils during periods of heavy rainfall. Neller (1946) recorded a 20 to 91% loss of applied phosphorus from Plummer fine sand and Leon fine sand that received superphosphate and calcined phosphate, while losses from

Norfolk fine sandy loam, Dunbar fine sandy loam, Bladen fine sandy loam, Amite fine sandy loam, and Coxville clay were almost negligible (Table 8). Ozanne _et_ _al_. (1961) noted the downward movement of 17 to 81% of applied phosphorus in a loamy sand that was under pasture and received only 22 inches of rainfall during the period of study.

Soils that are high in sesquioxide content fix greater amounts of phosphorus and thus prevent leaching losses. Larsen (1958) recorded decreased percolate losses of phosphorus with increased sesquioxide content from five organic soils.

Ozanne _et_ _al_. (1961) opined that leaching losses of phosphorus were related to the native phosphorus and organic matter content of the soil. They have shown (Table 12) that phosphorus losses would be minimal in soils with 100 ppm. of native phosphorus and which experienced 6% or more loss on ignition. Sandy soils, which are low in organic matter and native phosphorus, are also low in their phosphorus fixing capacity and hence, the greater percolate losses of phosphorus are in order.

There are conflicting opinions about the importance of lime in reducing phosphorus losses, but on acid Leon fine sand at least, it was effective. When Leon fine sand was limed to increase the P^H from 4.6 to 5.5, the phosphorus applied through different sources was reduced by 42.66%. Increasing the P^H to 6.35 has resulted in 97.23% reduced loss. Liming the acid sands to a P^H of 6.0 to 6.5 seems to greatly reduce the leaching losses of phosphorus.

The amount of available phosphorus in the soil at the time

leaching occurs has an effect on leaching losses. This in turn depends on the water-soluble phosphorus content, granule size, and quantity of phosphatic fertilizer applied. Neller (1946) recorded a higher loss of phosphate from superphosphate and calcined phosphate applications than from rock phosphate. Ninety-one and 81% losses were recorded from superphosphate and calcined phosphate applications, respectively, to unlimed Lakeland sand while different rock phosphate applications averaged to 40.81%. Similar trends were observed on limed soil as well at lower rates of loss (Table 13). Neller and Bartlett (1957) recovered 31.37 and 22.7% of the phosphorus applied as dicalcium and tricalcium phosphates to a Lakeland fine sand. The loss from rock phosphate applications was almost negligible (Table 11). Percolate losses were small, in general, from phosphorus carriers containing less water-soluble phosphorus. However, losses seem to be minimal at higher rates of application, from these sources. Neller (1946) recorded (Table 10) a decrease in the loss of phosphorus with increased applications of calcined and rock phosphate, whereas loss was maximal from medium rates of superphosphate application. In another trial, doubling the quantity of rock phosphate applied, resulted in 43.5 and 39% less loss of phosphorus from Leon fine sand.

The relative mobility of the cation associated with the phosphate radical also seems to control the mobility and loss of phosphorus from soils. Jacobson <u>et al</u>. (1948) experimenting with calcium, magnesium, potassium, and sodium dihydrogen phosphates noted (Table 9) a greater loss of phosphorus from sodium

dihydrogen phosphate, followed by potassium, magnesium, and calcium dihydrogen phosphate applications. This grouping is in the order of the relative mobility of the cations.

In general, the percolate losses of phosphorus from coarse textured soils could be prevented by the additions of organic matter, increasing the P^H to the range 6.0-6.5, keeping the soil under vegetation, and maintaining the available phosphorus at the required minimum with split applications of fertilizers.

Potassium

In soils, potassium is held as an exchangeable cation. It may also be fixed in non-exchangeable positions. Some may remain in the soil solution. Percolate losses of potassium rank next to nitrogen among the three major nutrients. Soil type, P^H, base exchange capacity, vegetation, rainfall, source and amount of fertilizer applied, are some of the factors that control leaching losses of potassium. Use of acid-producing nitrogen fertilizers may increase the leaching of potassium. There was a close correlation between nitrogen in the soil percolate and potassium (Allison et al., 1959). Raney (1960) observed a close association between nitrogen in leachates and potassium, calcium, and magnesium in leachates ($r = 0.994$; 0.902; 0.898) under different conditions.

Loss of native and applied potassium occurs from clay soils as well as sandy soils. Lyon and Bizzell (1918, 1936) found an average annual loss of 87.2, 73.3, and 60.6 pounds of potassium per acre, respectively, from fallows of Volusia silt loam,

Dunkirk clay loam, and Petoskey gritty sandy loam soils that did not receive any fertilizer potassium. Losses from unfertilized soils of fine texture are usually greater than from coarser soils because of the larger quantities of potassium present in soluble and exchangeable forms. The loss of applied potassium depends on the retentive ability of the soil, which in turn is mostly dependent on parent material and base exchange capacity. Relatively higher percent loss of potassium occurs from soils with low retentive capacities (Blume and Purvis, 1939). Stauffer (1942), and Stauffer and Rust (1954) recorded only small percolate losses of potassium from different silty clay soils that did not receive any fertilizer potassium, but loss of potassium was significantly correlated with percolated water.

Losses of applied potassium are greater from coarse textured soils as compared to fine textured soils. Volk (1940) noted 3 to 4 times higher loss of applied potassium from coarse soils as compared to a clay soil. In general, coarse textured soils permit greater percolate losses of water and have less nutrient retention ability. Soluble potassium is readily lost, followed by the loss of potassium released from the exchange complex, decomposing organic matter and dispersed humates (Kime, 1944). Kime noted a complete loss of easily leachable potassium from a sandy soil with an application of water equivalent to 4-acre inches of rain. Volk and Bell (1945) and Allison _et al_. (1959) demonstrated that such losses could be reduced 80 to 88% by cropping practices. This was found to be true on fine textured soils as well (Lyon and Bizzell, 1918, 1936; and Theron, 1964). Vegetative

cover on the soil constitutes the most important factor in controlling the percolate losses of potassium. Plants utilize soluble potassium to a considerable extent and also reduce the percolation of water.

Different crops, however, differ in their efficiency (Table 14) to reduce potassium losses. Crops must be present in adequate amounts to assimilate the available potassium and to afford a good ground cover. The relative utilization of potassium, however, like growth, varies among the different species. Broadbent and Chapman (1949), and Pratt and Chapman (1961) noted smaller losses of potassium from a soil cropped with vetch, as compared to the same soil cropped with mustard and melilotus.

The amount of soluble potassium present in the soil at the time heavy rains occur is also an important factor (Allison _et al._, 1959). This, to a large extent, is dependent on the quantity of applied potassium and fixing ability of the soils.

The movement and loss of potassium is also dependent upon the anion associated with potassium in the fertilizer. Loss of potassium seems to be greatest when the element is associated with sulfate and chloride as compared to carbonate, bicarbonate, and phosphate (MacIntire _et al._, 1945, 1952; Jacobson _et al._, 1948; Hogg and Cooper, 1964). The solubility and relative leachability of the associated anion seems to be an important factor.

The loss of potassium in leachates is also dependent on nitrogen and other associated elements in the soil. The application of nitrogen fertilizers has invariably increased the loss of potassium from soils (Jacobson _et al._, 1948; Broadbent and

Chapman, 1949; Pratt and Chapman, 1961). The increased acidity of the soil seems to be the factor involved. Among the effects of the different cations associated with the added nitrogen, sodium applications have produced increased losses of potassium, followed by calcium and magnesium. This is in order with the ability of those cations to replace potassium from the exchange complex of the soil. However, when an equivalent quantity of nitrogen was supplied as an ammonium salt, the loss of potassium was even greater. Here again, the greater acidity produced by the oxidation of ammonium salts seems to be the controlling factor.

The P^H of the soil is another important factor in controlling the loss of potassium, especially in soils with low base exchange capacity (Volk and Bell, 1944). Peech and Bradfield (1943) and Kime (1944) have indicated that leaching losses of potassium are enhanced at P^H's below 5.3 or above 6.0.

The application of limestone and dolomite, as compared to neutral salts of calcium, caused a repression in the leaching of potassium. Lyon and Bizzell (1918, 1936) reported that liming did not increase the amount of potassium in the soil solution as measured by leaching losses. MacIntire _et al_. (1945) noted reduced loss of potassium from two different soils with the application of limestone and dolomite. Blume and Purvis (1939) also observed smaller losses of potassium from limed soils but attributed the reduction to an improved granular condition of the soil brought on by the liming. In general, increased retention reflected in the smaller losses of potassium from limed soils may

be attributed to an increased P^H and replacement of exchangeable calcium by potassium.

Maintaining a good vegetative cover as completely as practicable, liming acid soils to a P^H of 5.3 to 6.0, and split applications of fertilizer potassium to the crops may significantly reduce percolation losses of potassium.

SUMMARY

The leaching of nitrogen, phosphorus, and potassium from soil constitutes a major source of loss of these nutrients in humid climates and from coarse-textured soils. The nature and mode of these losses can be summarized as follows:

(1) Under conditions of heavy rainfall, leaching losses are greater from fallow soils, coarse-textured soils, and soils rich in available nutrients.

(2) Liming may reduce leaching losses of phosphorus and potassium but not nitrogen. Liming to a P^H 6.0 to 6.5 seems to be best.

(3) Nitrogen and potassium dominate the leachates from most soil types. Considerable quantities of applied phosphorus may be recovered in percolates from coarse-textured soils.

(4) Nitrate is the dominant form of nitrogen in leachates. Other things being equal, nitrogen losses are greater from nitrate salts. In the decreasing order of leachability the nitrogen fertilizers can be arrayed in the following order: sodium nitrate, calcium nitrate, magnesium nitrate, ammonium nitrate, ammonium sulfate, ammonium chloride, urea, ammonium phosphate,

ammonium carbonate and insoluble organic fertilizers.

(5) Considerably more phosphorus may be lost when applied as a water-soluble phosphate fertilizer and in a finely ground form. Phosphorus losses are generally greater from soils containing less than 100 ppm. of native phosphorus and those soils losing less than 6% of their weight upon ignition.

(6) Soil potassium losses are greater when this element is applied as the sulfate and chloride. The addition of nitrogen fertilizers to the soil tends to increase the loss of potassium. Ammonium salts are especially effective in this role.

(7) By the improvement of soil structure with soil amendments, maintenance of an adequate vegetative cover, avoiding large fertilizer application during heavy rainfall periods, and by the use of split application of fertilizers to the standing crops, leaching losses of these three major elements may be markedly reduced.

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LITERATURE CITED

Allison, F. E. The enigma of soil nitrogen balance sheets. In A. G. Norman, ed. Advances in Agronomy, VII, Academic Press, Inc., New York, pp. 213-250. 1955.

Allison, F. E., Roller, E. M., and Adams, J. E. Soil fertility studies in lysimeters containing Lakeland sand. U.S.D.A. Tech. Bul. 1199. 1959.

Bear, Firman E. Soils and fertilizers. John Wiley and Sons, Inc., New York, p. 340. 1948.

Benson, Nels, and Barnette, R. M. Leaching studies with various sources of nitrogen. Jour. Amer. Soc. Agron. 31:44-54. 1939.

Bizzell, J. A. Comparative effects of ammonium sulfate and sodium nitrate on removal of nitrogen and calcium from the soil. Lysimeter Experiments V. Cornell Univ. Agr. Exp. Sta. Mem. 252. 1943.

__________. The effects of cropping and fertilization on the losses of nitrogen from the soil. Lysimeter Experiments VI. Cornell Univ. Agr. Exp. Sta. Mem. 256. 1944.

Black, C. A. Soil-plant relationships. John Wiley and Sons, Inc., New York, p. 251. 1957.

Blume, J. M., and Purvis, E. R. Fixation and release of applied potash on three coastal plains soils. Jour. Amer. Soc. Agron. 31:857-868. 1939.

Broadbent, F. E., and Chapman, H. D. A lysimeter investigation of gains, losses, and balance of salts and plant nutrients in an irrigated soil. Soil Sci. Soc. Amer. Proc. (1949) 14:261-269. 1950.

Brown, L. A. A study of phosphorus penetration and availability in soils. Soil Sci. 39:277-287. 1935.

Bryan, O. C. The accumulation and availability of phosphorus in old citrus grove soils. Soil Sci. 36:245-255. 1933.

Burns, G. R., and Dean, L. A. Movement of water and nitrate around bands of sodium nitrate in soils and glassbeads. Soil Sci. Soc. Amer. Proc. 28:470-474. 1964.

Chapman, H. D., Liebig, G. F., and Rayner, D. S. A lysimeter investigation of gains and losses under various systems of cover cropping and fertilization and a discussion of error sources. Hilgardia. 19:57-128. 1949.

Collings, Gilbert H. Commercial fertilizers and their sources and use. P. Blakiston's Son and Co., Inc., Philadelphia, p. 194. 1938.

Connecticut Agricultural Experiment Station. Report of the Director, 1929/30. Connecticut Agr. Exp. Sta. Bul. 322. 1931.

Converse, Charles D. Phosphorus fertility and movement studies on newly reclaimed sandy soil. Soil Sci. Soc. Amer. Proc. (1948) 13:423-427. 1949.

Cooke, G. W., and Gasser, J. K. R. Residual effects of phosphate fertilizers on a Wealden soil. Jour. Soil Sci. 6:248-253. 1955.

Dreibelbis, F. R. Some plant nutrient losses in gravitational water from monolith lysimeters at Coshocton, Ohio. Soil Sci. Soc. Amer. Proc. (1946) 11:182-188. 1947.

Drover, D. P. Losses of nitrogen and other soil constituents from two soils in filled in lysimeters (Abs.) Biol. Abstr. 45:6039. 1964.

Hagin, J. Comparison of availability of phosphorus from granulated and powdered superphosphate by calculation of yield curves related to the phosphorus added and found in soil and plant tests. Plant and Soil 9:114-130. 1957.

Harmsen, G. W., and Van Schreven, D. A. Mineralization of organic nitrogen in soils. In A. G. Norman, ed. Advances in Agronomy, VII, Academic Press, Inc., New York, pp. 299-398. 1955.

Hingston, F. J. The loss of applied phosphate and sulfur from soils under pasture in western Australia (Abs.) Biol. Abstr. 35:2198. 1960.

Hogg, D. E., and Cooper, Margery. Laboratory studies on losses of phosphorus, sulphur, and potassium from Te Kopuru sand. New Zealand Jour. Agr. Res. 7:364-374. 1964.

Jacobson, H. G. M., Swanson, C. L. W., and Smith, Evelyn. Effect of various fertilizer cations and anions on soil reaction, leaching, nitrification of urea and related characteristics in an uncropped soil. A report on Windsor lysimeter Series E. Soil Sci. 65:437-460. 1948.

Jenny, Hans, and Shade, E. R. The potassium-lime problem in soils. Jour. Amer. Soc. Agron. 26:162-170. 1934.

Johnston, William R., Ittihadieh, F., Daum, Richard M., and Pillisbury, Arthur F. Nitrogen and phosphorus in tile drainage effluent. Soil Sci. Soc. Amer. Proc. 29:287-289. 1965.

Jones, Randall J. Nitrogen losses from Alabama soils in lysimeters as influenced by various systems of green manure crop management. Jour. Amer. Soc. Agron. 34:574-585. 1942.

Kime, Chas. D. Jr. Leaching of potash from a sandy citrus soil of Florida. Citrus Ind. 25:3. 1944.

Kohnke, Helmut, Dreibelbis, F. R., and Davidson, J. M. A survey and discussion of lysimeters and a bibliography on their construction and performance. U.S.D.A. Misc. Pub. 372. 1940.

Larsen, J. E., Langston, Ruble, and Warren, G. F. Studies on the leaching of applied labeled phosphorus in organic soils. Soil Sci. Soc. Amer. Proc. 22:558-560. 1958.

Lutz, J. A. Jr., Rich, C. I., and Obenshain, S. S. Penetration of top-dressed phosphate in the soil as influenced by source, rate, and time of application and by irrigation. Virginia Agr. Exp. Sta. Tech. Bul. 125. 1956.

Lyon, Lyttleton T., and Bizzell, James A. Lysimeter Experiments. Records for tanks 1-12 during the years 1910-1914, inclusive. Cornell Univ. Agr. Exp. Sta. Mem. 12. 1918.

__________, and __________. Records for tanks 17-20 during the years 1922-1933, and for tanks 13-16 during the years 1913-1928. Lysimeter Experiments IV. Cornell Univ. Agr. Exp. Sta. Mem. 194. 1936.

MacIntire, W. H., Shaw, W. M., and Robinson, Brooks. The divergent behavior of KPO_3 and K_2SO_4 in soils, with and without limestone and dolomite. Soil Sci. 59:155-162. 1945.

__________, __________, __________, and Young, J. B. Potassium retention from annual additions of chloride, sulfate, and nitrate as influenced by limestone and by dolomite. Soil Sci. 55:321-332. 1943.

__________, __________, and Sanders, K. B. The influence of liming on the availability of soil potash. Jour. Amer. Soc. Agron. 19:483-505. 1927.

__________, Young, J. B., and Shaw, W. M. Base interchange induced by calcium, magnesium, and sodium nitrates in a 6-foot column of soil-subsoil. Soil Sci. 35:49-53. 1938.

MacIntire, W. H., Young, J. B., Shaw, W. M., and Robinson, B. Nitrogen recoveries from applications of ammonium chloride, phosphate and sulfate and outgo of complementary ions in rainwater leachings through a 6-foot soil-subsoil column. Soil Sci. Soc. Amer. Proc. 16:301-306. 1952.

MacKay, D. C., and Eaton, J. B. The penetration of radioactive superphosphate into a podzol soil. Can. J. Soil Sci. 39: 215-221. 1959.

Mann, Harold H., and Barnes, T. W. Studies of soil after fifty years of wheat or barley cropping, especially of soil made acid with sulphate of ammonia. J. Agric. Sci. 30:345-386. 1940.

Midgley, A. R. The movement and fixation of phosphates in relation to permanent pasture fertilization. Jour. Amer. Soc. Agron. 23:788-799. 1931.

Morgan, M. F. Soil changes resulting from nitrogenous fertilization. Connecticut Agr. Exp. Sta. Bul. 384. 1936.

__________, Jacobson, H. G. M., and LeCompte, S. B. Jr. Drainage water losses from a sandy soil as affected by cropping and cover crops. Windsor lysimeter Series C. Connecticut Agr. Exp. Sta. Bul. 466. 1942.

Mooers, C. A., MacIntire, W. H., and Young, J. B. The recovery of soil nitrogen under various conditions as measured by lysimeters of different depths. Tennessee Agr. Exp. Sta. Bul. 138. 1927.

Neller, J. R. Mobility of phosphates in sandy soils. Soil Sci. Soc. Amer. Proc. (1946) 11:227-230. 1947.

__________, and Bartlett, F. D. Effect of particle size on availability and mobility of fused tricalcium phosphate and rock phosphate compared with other phosphates in contrasting soil types. Soil Sci. Soc. Amer. Proc. 21:189-192. 1957.

__________, Jones, D. W., Gammon, Nathan Jr., and Forbes, R. B. Leaching of fertilizer phosphorus in acid sandy soils as affected by lime. Florida Agr. Exp. Sta. Circ. S-32. 1951.

Nelson, Werner L., and Stanford, George. Changing concepts of plant nutrient behavior and fertilizer use. In A. G. Norman, ed. Advances in Agronomy, X, Academic Press, Inc., New York, pp. 67-141. 1958.

Owens, L. D. Nitrogen movement and transformations in soils as evaluated by a lysimeter study utilizing isotopic nitrogen. Soil Sci. Soc. Amer. Proc. 24:372-376. 1960.

Ozanne, P. G., Kirton, D. J., and Shaw, T. C. The loss of phosphorus from sandy soils. Aust. J. Agric. Res. 12:409-423. 1961.

Peech, Michael. Chemical studies on soils from Florida citrus groves. Florida Agr. Exp. Sta. Bul. 340. 1939.

__________, and Bradfield, Richard. The effect of lime and magnesium on the soil potassium and absorption of potassium by plants. Soil Sci. 55:37-48. 1943.

Peterburgsky, A. V., and Yanishevsky, F. V. Transformation of forms of potassium in soil during long-term potassium fertilization. Plant and Soil 15:199-210. 1961.

Pratt, P. F., and Chapman, H. D. Gains and losses of mineral elements in an irrigated soil during a 20-year lysimeter investigation. Hilgardia 30:445-467. 1961.

__________, Jones, W. W., and Chapman, H. D. Changes in phosphorus in an irrigated soil during 28 years of differential fertilization. Soil Sci. 82:295-306. 1956.

Raney, W. A. The dominant role of nitrogen in leaching losses from soils in humid regions. Jour. Amer. Soc. Agron. 52: 563-566. 1960.

Reitemeier, R. F. Soil potassium. <u>In</u> A. G. Norman, ed. Advances in Agronomy, III. Academic Press, Inc., New York, pp. 113-164. 1951.

Schaller, F. The downward movement of lime and superphosphate in relation to permanent pasture fertilization. Soil Sci. Soc. Amer. Proc. (1940) 5:162-166. 1941.

Sell, O. E., and Olson, L. C. The effect of surface applied phosphate and limestone on soil nutrients and P^H of permanent pasture. Soil Sci. Soc. Amer. Proc. (1946) 11:238-245. 1947.

Sen Gupta, H. B., and Cornfield, A. H. Phosphorus in Calcareous Soils, IV. Nature of and factors influencing the fixation of added phosphate. J. Sci. Food Agric. 14:873-877. 1963.

Stauffer, R. S. Runoff, percolate and leaching losses from some Illinois soils. Jour. Amer. Soc. Agron. 34:830-835. 1942.

__________, and Rust, R. H. Leaching losses, runoff, and percolate from eight Illinois soils. Jour. Amer. Soc. Agron. 46:207-211. 1954.

Stephenson, R. E., and Chapman, H. D. Phosphate penetration in field soils. Jour. Amer. Soc. Agron. 23:759-770. 1931.

Theron, J. J. Lisemeterproewe II: 1945-1961 (In French). S. Agr. Tydskr. Landbouwet. 7:109-122. English Summary. 1964.

Truog, Emil, and Jones, Randall J. Fate of Soluble potash applied to soils. Ind. and Eng. Chem. 30:882-885. 1938.

Volk, Gaylord H. Efficiency of various nitrogen sources for pasture grasses in large lysimeters of Lakeland fine sand. Soil Sci. Soc. Amer. Proc. 20:41-45. 1956.

__________, and Bell, C. E. Some major factors in the leaching of calcium, potassium, sulfur, and nitrogen from sandy soils. A lysimeter study. Florida Agr. Exp. Sta. Bul. 416. 1945.

__________, and __________. Effect of anion balance on the leaching of ions from sandy soils. Soil Sci. Soc. Amer. Proc. (1947) 12:188-190. 1948.

Volk, N. J. The effect of soil characteristics and winter legumes on the leaching of potassium below the 8-inch depth in some Alabama soils. Jour. Amer. Soc. Agron. 32:888-890. 1940.

Wadleigh, W. H., and Richards, L. A. Soil moisture and the mineral nutrition of plants. In. Emil Truog, ed. Mineral nutrition of plants. University of Wisconsin Press, pp. 411-450. 1953.

LYSIMETER STUDIES ON THE LEACHING LOSSES OF NITROGEN, PHOSPHORUS, AND POTASSIUM

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AN ABSTRACT OF A MASTER'S REPORT

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Losses of plant nutrients via leaching constitutes a major source of soil depletion. Such losses are of considerable magnitude in regions of heavy rainfall and from coarse textured, permeable soils.

Nitrogen in the form of nitrate is the dominant element in soil leachates. Sizeable quantities of potassium are also removed by the soil solution. Phosphorus, of the three elements nitrogen, phosphorus, and potassium, is least susceptible to leaching due to the fixation of this element in most soils.

Leaching losses of essential plant nutrients may be curtailed to some extent by improving the soil structure and by maintaining a good vegetative cover. Split applications of fertilizer according to crop needs tend to retard losses of applied nutrients.